

*B1
concl*
semiconductor layers, an interface of said wafer-bond layer with the semiconductor layers exhibiting properties characteristic of layers that have undergone wafer bonding, (including being mechanically robust;) and electrode means for applying a current to said arrangement of semiconductor layers.

Claim 18, line 2 delete "low resistance electrical connection" and insert --conductive ohmic bond--.

REMARKS

Applicants acknowledge that the disclosure as filed has numerous words wherein individual letters are partially illegible. The ones particularly remarked upon by the Examiner have been corrected by this amendment. However, applicants believe that the few remaining illegible letters do not present the reader with any difficulty in reading the words with those illegible letters nor do any of these partially illegible words present the reader with any difficulty in fully understanding the specification and claims.

Claim 18 has been amended to specify that the wafer bond forms a conductive ohmic interface with the light emitting layers. The disclosure fully supports the term "conductive ohmic interface/bond". Moreover, even the claim's original wording, "low resistance", was fully supported by both the specification and the common meaning of that term in this art.

The particular subject of low resistance wafer bonding was addressed in "High-Power GaN P-N Junction Blue Light Emitting Diodes" by S. Nakamura, et al., Jap. Journ. Appl. Phys. 30, 1998-2001(1991). The article stated that, "Generally, it is necessary for the forward voltage of LEDs to be less than 5V because the voltage of the DC power supply of electronic circuits is 5V."

The low resistance electrical connection between the

semiconductor wafer bond layer to the semiconductor must facilitate operation of the light emitting semiconductor device at <5V. The forward voltage, V_f , of an LED has two components, the junction voltage V_j and the dynamic resistance R_d . Thus, $V_f = V_j + IR_d$, where I is the operating current. I is typically <50mA (see Optoelectronic Designer's Catalog, Hewlett-Packard, 1993). V_j is characteristic of the material which comprises the light emitting active region of the device (typically 1-3V) and R_d is the sum of all resistive elements in the LED (e.g. wafer bond interface resistance, contact resistance, bulk semiconductor resistance, etc.). In the limiting case, the forward voltage is restricted to 5V, the maximum operating current is 50mA, and the junction voltage is typically 2V, restricting $R_d < (5V - 2V) / 50 \text{ mA} < 80\Omega$.

In the limiting case, R_d consists of the contributions solely from the wafer bond interface, resulting in the definition of the low resistance wafer bond interface to be one that contributes a series resistance of <80 Ω dynamic resistance in LED device operation. This same definition applies to ohmic bonds and is fully supported by the specification.

Ideally the wafer bonded interface should have as low a resistance as possible. Examples of desirable low resistance wafer bonding are cited in the "Reduction to Practice" section of the current disclosure. Accordingly, 1.5-5 Ω s comprises a low resistance interface for 20X20 mil chips. Typical LED chips range from 5X5 mils to 20X20 mils. The 5 Ω resistance of the 20X20 mil chip scales to 80 Ω for the smallest 5X5 mils LED chip, in accordance with the previous discussion. With this additional clarification, which applicants do not believe comprises new matter, claim 18 should now be allowable form.

Claims 14 through 21 were rejected under 35 U.S.C. § 103 as unpatentable over Fletcher et al., U. S. Patent No. 5,008,718 ("Fletcher") in view of Jokerst et al., U.S. Patent No.

5,280,184("Jokerst").

Applicants believe that the light emitting semiconductor devices they claim in claims 14 through 21 are distinguishable from the combination of Fletcher and Jokerst and not made obvious by them.

As claimed in amended claim 14, the only independent claim in the present invention, the semiconductor device has a plurality of semiconductor layers which generate light in response to a current and an optically transparent layer which is wafer bonded to the semiconductor layers, the wafer bond being mechanically robust. Mechanically robust is herein defined as having good mechanical strength, as discussed in the specification. Neither reference teaches such devices.

Fletcher discloses an LED with a transparent window layer. The LED consists of a light emitting AlGaInP active region and a thick GaP top transparent window layer, both formed by epitaxial crystal growth on an absorbing GaAs substrate. After growth, the GaAs substrate is removed and, if desired, a thick transparent GaP layer is formed in its place by epitaxial growth techniques. Such structures have been known for a long time in this art(see Ishiguro, Hisanori, et al. "High Efficient GaAlAs light emitting diodes of 660nm with a double heterostructure on a GaAlAs substrate", Appl. Phys. Lett. 43(11), 12/01/83, pp. 1034-1036). Nothing in the Fletcher reference suggests or even hints at the forming of the bond between the light emitting semiconductor layers and the transparent substrate using wafer bonding techniques. Certainly, nothing in the reference teaches how to form a mechanically robust, transparent bond between these layers using wafer bonding techniques, as is claimed in claim 14.

Jokerst describes various semiconductor devices fabricated using two very specific types of wafer bonding, epitaxial lift off followed by van der Waal's bonding and epitaxial lift off followed by metal to metal annealing, and the ability to align

and selectively deposit devices. These methods are applied in three dimensional ICs to facilitate complex system integration while preserving the high material quality of lattice matched growth.

The van der Waal's bonding used in Jokerst does not form a conductive bond as claimed in claim 18. As enumerated in both Jokerst and the disclosure of the present invention, van der Waal's bonding provides poor electrical connection between the bonded surfaces. The van der Waal's bonding methods taught by Jokerst simply do not create a device similar to that claimed in amended claim 14, nor does Jokerst even hint at the wafer bonding techniques taught in the present invention to form ohmic bonds between the transparent layer and the light emitting layer.

Moreover, the van der Waal's bonding in Jokerst does not provide a robust bond between the layers. The van der Waal's forces are relatively small and the bonds formed by them are easily broken. They are simply not "mechanically robust".

The second method of wafer bonding taught by Jokerst, metal to metal annealing, does provide a good electrical connection between the bonded surfaces. However, the interface created by the annealing is opaque. This contrasts with the interface in claim 14, which is optically transparent and mechanically robust.

Although the van der Waal's wafer bonding technique taught by Jokerst may facilitate good crystal quality and optical transparency, it is simply inadequate to create a strong, mechanically robust, conductive bond.

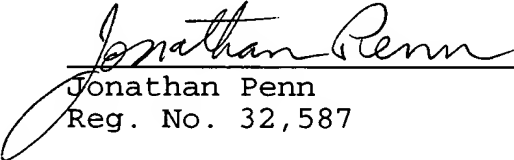
Unlike Jokerst, the devices claimed in the present invention have a robust, transparent interface, which in some embodiments allows current flow. The interface is physically strong and allows full light transmission. As Fletcher teaches absolutely nothing about wafer bonding, and therefore does not enable the fabrication of a device using wafer bonding techniques and as Jokerst does not teach how to form a mechanically robust,

transparent interface, their combination does not make any aspect of the present invention obvious.

In light of the amendments to the specification and the claims and the preceding remarks, review of pending claims 14 through 21 is requested. The prompt issuance of a notice of allowance for the claims is also respectfully requested.

Yours truly,

Fred A. Kish, et al.


Jonathan Penn
Reg. No. 32,587

Date: 4/25/95
Hewlett-Packard Company
• IP Administration
• Legal Department, M/S 20B0
• P.O. Box 10301
• Palo Alto, CA 94303-0890